Event-related potentials study on cross-modal discrimination of Chinese characters *

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Abstract Event-related potentials (ERPs) were measured in 15 normal young subjects (18—22 years old) using the "cross-modal and delayed response" paradigm, which is able to improve inattention purity. The stimuli consisted of written and spoken single Chinese characters. The presentation probability of standard stimuli was 82.5% and that of deviant stimuli was 17.5%. The attention components were obtained by subtracting the ERPs of inattention condition from those of attention condition. The results of the N1 scalp distribution demonstrated a cross-modal difference. This result is in contrast to studies with non-verbal as well as with English verbal stimuli. This probably reflected the brain mechanism feature of Chinese language processing. The processing location of attention was varied along with verbal/non-verbal stimuli, auditory/visual modalities and standard/deviant stimuli, and thus it has plasticity. The early attention effects occurred before the exogenous components, and thus provided evidence supporting the early selective theory of attention. According to the relationship of N1 and Nd1, the present result supported the viewpoint that the N1 enhancement was caused by endogenous components overlapping with exogenous one rather than by pure exogenous component.

Keywords: event-related potential (ERP), early negative difference wave (Nd1), selective attention, Chinese character, cross-modal and delayed response paradigm.

The use of language stimuli in event-related potentials (ERPs) studies of selective attention is a relatively new development. Recently, there have been a few ERP research reports about selective attention evoked by Western languages. Its cross-modal ERP research on selective attention is even more sparse. Otten et al.[1] studied repetition effects on ERPs to visually presented words. They found that a positive-going repetition effect occurred, in which at least one of the two presentations of the repeated words was attended. More recently, Bentin et al.[2] used a dichotic selective listening task to observe ERPs evoked by attended and unattended words. An N1 with a peak latency of about 100 ms, and an N400 occurring between 400 and 600 ms were observed. The N400 effect (the N400 amplitude elicited by related words was lower than that by the unrelated words) in the unattended ear decreased compared with that in the attended ear. The similar N400 effects were obtained while recognizing the related and unrelated words of semantics. Trejo et al.[3] compared ERPs elicited by tones with that by spoken words. The objects of these studies were P300, N400, etc., which are late components as opposed to the N1 component. The study of selective attention on Chinese language has not been reported until now. In addition, the cross-modal ERP studies on semantic processes mainly aimed at the relationship of modalities. There are two different standpoints, the conversion hypothesis and the common semantic system hypothesis[4]. The former considered that words were converted from one modality to another during reading or possibly during a listening period. However, the common semantic system hypothesis

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argues that while written and spoken words were processed in their own respective perceptual and lexical systems, they activated meaning in a common semantic or conceptual system[4,5]. The foregoing studies were primarily concerned with semantic modality conversion as well as process mechanisms rather than the role of selective attention between modalities. There is a long standing question regarding early selection and late selection, which has been proposed on the basis of presumed filters during different attention states[6—8]. The line of demarcation between early and late selective attention theories hinges on whether selection occurs before or after perceptual processing[9]. The controversy of selective attention continues and is a basic, yet difficult problem in the psychology of attention. Very recently, Wei and Luo[9] suggested a theoretical proposal, stating that the position of attentive selection in cognitive processing can be changed. As a metaphor, it could be likened to an information filter whose filter hole diameter has plasticity. The diameter of the hole is decided by the conditions inside and outside of the human organism. This hypothesis necessarily requires more research results to gain support. In the non-verbal studies on selective attention, a divergence of views on the N1 enhancement yielded by attention effects has existed for a long time. Hillyard et al.[6] suggested that the "N1 effect" is caused by a genuine enhancement of the exogenous N1 component, but Naatanen et al.[7] argued that it is caused by an endogenous processing negativity overlapping with the exogenous components. The controversy is unresolved up to today[8] and further study is needed.

The present experiment investigated the ERPs of selective attention with language, using the "cross-modal and delayed reaction" paradigm to further purify the inattention condition. The goal was to provide experimental evidence and explicate the cause of the N1 enhancement, the plasticity of attention filter location, the cerebral mechanisms of Chinese language processing, and the controversy of early- and late-selection theory of attention.

1 Methods

1.1 Subjects

Fifteen undergraduates, 18—22 years of age (10 males, 5 females) were paid to serve as subjects in the experiment. All of them were right handed as measured by the Reitain' Test[10], with normal hearing and vision or corrected visual acuity.

1.2 ERP recording

The EEG was recorded at 17 electrodes of international 10—20 EEG system electrodes using the electrode-cap (as shown in fig. 1) on the scalp with the reference on the left and right mastoids. The vertical and horizontal EOG (VEOG, HEOG) were recorded. The other recording parameters were similar to those in the non-language experiment[11,12].

1.3 Stimulus

1.3.1 Visual stimuli. The Chinese single-words were selected from "The Feature Information Database of Chinese Characters"[13]. The visual deviant stimuli were composed of 60 Chinese characters with a few strokes (5—7 strokes) and up-down structure. The standard stimuli used 283 characters including 3 kinds: few strokes and left-right structure, many strokes (12—15 strokes) and up-down structure, many strokes and left-right structure. The presentation probability of the deviant stimuli was 17.5% and that of the standard stimuli was 82.5%.

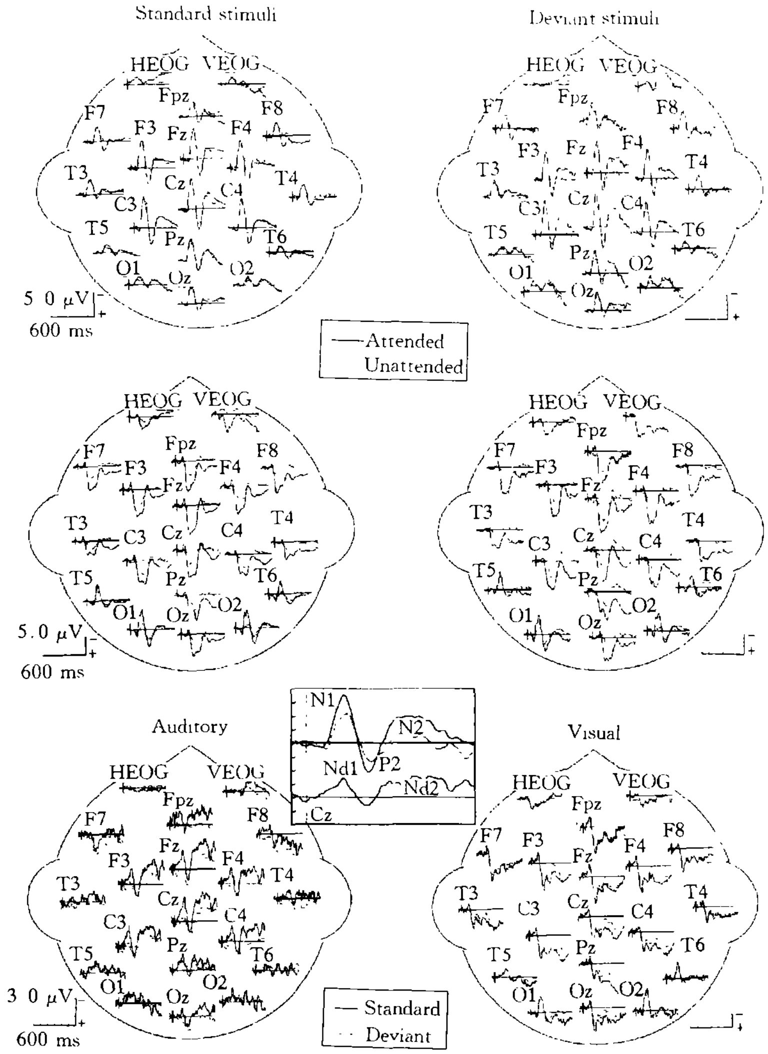

Fig. 1 Top: Grand average ($n = 15$) ERP waveform elicited by auditory standard (left) and deviant (right) stimuli under attention (solid line) and inattention (dashed line) conditions. Middle: Grand average ERPs waveform elicited by visual standard (left) and deviant (right) stimuli under attention (solid line) and inattention (dashed line) conditions. Bottom: Difference waveform elicited by deviant (solid line) and standard (dashed line) stimuli in the auditory (left) and visual (right) modality. Insert: Attend auditory deviant stimuli, at Cz site. Difference = attended ERP-unattended ERP.

1.3.2 Auditory stimuli. The Chinese syllable is composed of an initial consonant and a simple or compound vowel. The auditory deviant stimuli were 60 single words including the vowels a, ai, an, ang and ao. The standard stimuli were 283 words with other vowels. The auditory stimuli were spoken by a female Mandarin-speaker and were recorded with the STIM software of NeuroScan. The presentation probability of standard and deviant stimuli was the same as the visual stimuli. The mean duration of standard stimuli was (177.3 ± 27.4)ms and the mean duration of deviant stimuli was (175.9 ± 35.9)ms. The t test did not show any significant differences between them ($t = 0.26$, $P < 0.792$).

1.4 Task and procedure

1.4.1 Experiment 1: Auditory task. Earplugs were inserted in the subject's ears and the stimuli from the earplugs were delivered through air tubes. The distance between the screen and subjects' eyes was 1.3 m. The sequence of stimuli which was presented to every subject was: attended modality's standard and deviant stimuli, response imperative signal, and unattended modality's standard and deviant stimuli. Each attended standard or deviant stimulus followed an imperative response signal. Between each stimulus and imperative response signal of attended modality, 0—2 stimuli of unattended modality were randomly inserted. The auditory stimuli were spoken character as mentioned above and the imperative signals were clicks (2 ms, 24 dB, SPL). The visual stimuli were Chinese words of single-character presented on the center of the computer screen (4 cm × 4 cm). Only one character was presented for every trial. Both the presentation order of the standard and deviant stimuli in each modality and the order of the stimuli of two modalities were pseudo-random. Interstimulus interval (ISI) was 250—700 ms (onset to onset) pseudo-randomly. The subjects were instructed to fixate on the central point of the screen but to attend to the spoken character rather than the written character. They were asked to prepare to press the button with one thumb when standard stimuli appeared and with the other thumb when deviant stimuli appeared. When the imperative response signal (click) appeared, they were asked to press the button as soon as possible. ERPs to attended auditory stimuli and unattended visual stimuli were obtained in this experiment.

1.4.2 Experiment 2: Visual task. The subjects were instructed to pay attention to the visual stimuli (the Chinese character of screen) rather than to the spoken character. Each attended standard or deviant stimulus followed a visual imperative response signal, which was a small red cross (0.5 cm × 0.5 cm). There was not the auditory imperative signal (click). The remainder of the procedure was the same as for experiment 1.

1.5 Data analysis and statistics

The EEG evoked by two types of auditory stimuli and two types of visual stimuli under attention and inattention conditions was averaged separately, resulting in 8 types of ERPs. The difference waves were obtained by subtracting ERPs of the standard and the deviant stimuli under the inattention condition from ERPs recorded under the attention conditions (see the enlarged plate in the button of fig. 1). The ERP components were named on the basis of polarity and peak latency of waveforms. The auditory P70, N140, P230, N350 and P540 and visual P90, N160, P220, N350 and P500 appeared. According to the purpose of the present experiment and previous reports[14] the N1 and early negative difference wave (Nd1) were measured. The mean amplitudes of Nd1 were obtained over consecutive 20-ms intervals from 60 ms to 200 ms post-stimulus. The onset time of N1 and Nd1 was their separation from the pre-stimulus baseline. For the dependent variable of the Nd1 onset, a $2 \times 2 \times 3 \times 17$ repeated measures MANOVA was conducted using the SPSS software package. The factors were modality (2 levels: auditory and visual modalities), stimulus type (2 levels: standard and deviant stimuli), ERP components (3 levels: attended N1, unattended N1 and Nd1), and electrodes (17 levels). The P values were corrected by the Greenhouse-Geisser method. ERP distributions were normalized by dividing the amplitudes at each electrode by the sum of the squared amplitude at all recording sites[15].

2 Results

2.1 Basic ERP components

In the auditory modality, the P70, N140, P230, N350 and P540 components were elicited by standard and deviant stimuli under both attention and inattention conditions. As shown in the top of fig. 1, the N140, P230 and N350 were most obvious. All of their largest peaks were distributed over the vertex. The greatest peak of P70 was located at the vertex in attention, and at the frontal sites in inattention. The largest P540 was located at the parietal and occipital areas, its amplitudes reduced to the standard stimuli or under inattention condition. In the visual modality (the middle of fig. 1), the P90, N160, P220, N350 and P500 were yielded by both standards and deviants regardless of the attention or inattention conditions. An early negativity, N160, was mainly distributed at two lateral occipital and posterior temporal sites, and a late negativity N350 at the fronto-central area. Moreover, the P90 was at the occipital site and larger in the left; the P220 was broadly distributed at the central, frontal, parietal and occipital areas, and its largest peak was at central line of the frontal area; the P500 was mainly at the parietal-occipital site in attention, its amplitude was not obvious under inattention condition.

2.2 N1 component

The N1 (auditory N140 and visual N160) component in the present experiment was closely related to attention, and thereby was the important target component in this research. The result showed that the greatest N1 elicited by attended auditory deviant stimuli occurred during 121—140 ms post-stimulus and was located at the vertex (-6.66 μV, Cz, hereinafter amplitude and electrode site). The distribution of the unattended N1 was located on the left of the central area (C3, -4.84 μV). The attentive N1 evoked by auditory deviant stimulus was located also at the left central site (C3, -6.17 μV), and the unattended N1 was at the frontal site (Fz, -6.19 μV). The greatest peak of these three components appeared slightly further later (141—160 ms). The largest N1 in the visual modality appeared slightly later (161—180 ms) than that in the auditory modality, and all of them were distributed at the left occipital sites.

The sample-paired t test was conducted for the N1 amplitude between attention and inattention conditions. The attended N1 amplitudes were significantly (or nearing significant level) larger than unattended N1 at location as follows: for the auditory deviant stimuli, Fpz ($t=2.30$, $P<0.037$), Fz(3.25, 0.006), F3(2.80, 0.014), F4(2.54, 0.024), Cz(3.62, 0.003), C3 (3.59, 0.003), Pz(2.64, 0.019), Oz(2.18, 0.047) during 121—140 ms, and Fz(2.14, 0.037), Cz(2.75, 0.016) during 141—160 ms; for the auditory standards (141—160 ms), T5 (3.37, 0.005), T6(2.04, 0.061), O1(3.06, 0.008) and O2(2.68, 0.018); for the visual deviants (160—180 ms), O1(2.09, 0.056) and O2(2.10, 0.054); for the visual standards (161—180 ms), T5(2.45, 0.028), T6(2.46, 0.028), O1(3.44, 0.004) and O2(3.18, 0.007). In addition, in the visual modality the other electrode location showed that attended P2 (P220) was significantly greater than unattended P2.

2.3 Attentive component (Nd1)

The attentive component was obtained by subtracting unattended ERPs from attended ERPs for the same kind of stimulus and modality. The bottom of fig. 1 is the grand-average of difference waves. The peak latency of Nd1 elicited by auditory standard stimuli was 161—180 ms; its largest peak was at the left occipital area (O1, − 1.05 μV). The Nd1 evoked by auditory deviant stimulus was located at Cz, and the peak was obviously increased and advanced (− 2.64 μV, 121—140 ms). The mean amplitudes of the Nd1 yielded by the visual standards during 121—140 ms, 141—160 ms and 161—180 ms were − 3.87, − 3.61 and − 3.58 μV respectively. Their largest peaks were distributed on the right occipital site (O2). The largest Nd1 peak elicited by the visual deviants occurred during 141—160 ms, which was located on the left occipital site (O1, −3.01 μV).

2.4 Onset of N1 and Nd1

Table 1 shows the onset time of attended N1, unattended N1 and attentive component Nd1 on the location of their largest peak. The MANOVA results demonstrated that there were main effects on the modality [$F_{(1,14)} = 14.14$, $P < 0.002$], stimulus type [$F_{(1,14)} = 106.51$, $P < 0.0001$], ERP component [$F_{(2,28)} = 73.55$, $P < 0.0001$] and electrode site [$F_{(16,224)} = 31.76$, $P < 0.0001$]. In addition, there was a significant interaction between modality and electrode site [$F_{(16,224)} = 14.20$, $P < 0.0001$]. The paired t tests of the onset between attended N1 and Nd1, or unattended N1 and Nd1 were conducted. Table 2 shows the locations on which the difference attained significant level in statistics.

Table 1 The onset time of N1 and Nd1 (ms)

Mod.	Stimulus	Attended N1		Unattended N1		Nd1	
		site	onset	site	onset	site	onset
Aud.	stand.	C3	66.7±13.3	Fz	74.9±14.5	O1	54.4±18.3
	devi.	Cz	62.5±14.5	C3	75.6±12.4	Cz	43.5±11.4
Vis.	stand.	O1	93.9±20.3	O1	117.8±26.2	O2	80.2±16.6
	devi.	O1	96.3±11.9	O1	106.6±18.7	O1	82.5±17.2

aud. = auditory, mod. = modality, stand. = standard, devi. = deviant

Table 2 Comparison of onset time among attended N1, unattended N1 and Nd1

Mod.	stim.	Attended N1-unattended N1	Attended N1-Nd1	Unattended N1-Nd1
Aud.	stand.	Fz, Cz, T3, T4, T6, Pz, O2; t: 2.15 (Cz)—3.66 (O2), P: 0.022—0.003	Fpz, F4, F7, F8, C3, T4, T5, T6, Pz, Oz, O1; t: 2.34 (F8)—3.95 (Oz), P: 0.034—0.001	all sites: 2.51 (C4)—6.96 (Oz), P: 0.025 (0.000 1, except T5 (2.08, 0.056) and Pz (1.99, 0.066)
	devi.	Fpz, F3, Cz, C3, T4, T5, T6, Oz, O1; t: 2.56 (F3)—3.58 (O1), P: 0.023—0.003	all sites; t: 2.27 (T3)—5.96 (Fz), P: 0.040—0.000 1	all sites; t: 4.73 (O2)—14.03 (C3), P<0.000 1
Visual	stand.	all sites; t: 2.26 (Pz)—5.04 (Fz) P: 0.015—0.000 1, except C3 (2.06, 0.059)	C3, T3, T5, T6, O1, O2; t: 2.17 (O1)—5.24 (T6), P: 0.047—0.000 1	all sites; t: 2.76 (F3)—6.03 (T5), P: 0.015—0.000 1
	devi.	only O1 attains significant level (1.90, 0.079)	all sites; t: 2.83 (Pz)—5.09 (F3), P: 0.013—0.000 1	all sites; t: 2.36 (Oz)—5.01 (T6), P: 0.033—0.000 1

Aud. = auditory, Mod. = modality, Nd1 = early negative difference, Stand. = standard, Stim. = stimulus, Devi. = deviant.

3 Discussion

3.1 The feature of ERP basic components of Chinese processing

The present experiment involved Chinese form and sound discrimination (visual and auditory) tasks, attention and inattention conditions, and standard and deviant stimuli, under all eight conditions. The present result demonstrated that the scalp distribution of the basic ERP components is consistent with our previous experimental results[11,12,16] and therefore the present result is reliable. In the present experiment the scalp distribution of the N1 clearly presented a cross-modal difference. The largest peak of the auditory N1 was located over the central area and the visual N1 peak was at two-lateral occipital sites. These scalp distributions were different with the N1 elicited by non-verbal stimulus, which was generally distributed at the frontal site[16]. This result is different from that of English. For the ERPs evoked by cross-modal English words, the largest N1 was located at frontal-central sites regardless of auditory and visual modality[4,5]. The visual basic ERP components except N1 in the present experiment are similar to the English result of Otten et al. The present result suggests that the difference of N1 scalp distribution between modalities probably reflects the characteristics of brain mechanism in the processing of Chinese language. The primary processing of the form of the Chinese word probably occurred at the primary visual center (two lateral occipital areas), but for the sound of the Chinese word it occurred at the regulation center (vertex) rather than the primary auditory center (temporal area). However, this is merely the primary evidence from electrophysiology and it remains to be proven by the brain function image research and so on.

3.2 Early attentive component and its plasticity of processing location

An obvious early attentive component Nd1 was obtained by subtracting unattended ERPs from attended ERPs. (i) The peak latency was between 121 and 180 ms, the Nd1 elicited by deviant stimuli (121—140 ms) was earlier than that by standards (161—180 ms) in the auditory modality. There was no difference in peak latency between stimulus type in the visual modality. Only in visual modality the Nd1 duration was longer for the standard stimuli. (ii) The Nd1 amplitude in the visual modality was larger than that in the auditory modality. With regard to the stimulus type, the Nd1 elicited by the auditory deviants was greater when compared with the Nd1 elicited by standards, but this was contrast to the visual modality. (iii) For deviant stimuli, the largest peak of Nd1 evoked by auditory stimuli was distributed at the vertex, and the largest peak of Nd1 by visual stimuli was at the occipital sites. For standard stimuli, the Nd1 evoked by both auditory and visual modalities was at the occipital sites. For the attentive component of non-verbal stimulus in our previous experiment[16], the distribution of deviant-related Nd1 showed a modality specificity such that the auditory Nd1 was located at the temporal and the visual Nd1 was at occipital area. The Nd1 elicited by non-verbal stimulus standard stimuli regardless of the auditory or visual modality were located at the fronto-central area. The foregoing results are displayed in table 3 as a comparison with the present results.

Table 3 Comparison of the largest Nd1 peak

Modality	Non-language		Language	
	deviant	standard	deviant	standard
Auditory	temporal	frontal	central	occipital
Visual	occipital	frontal	occipital	occipital

As shown in table 3, the processing location of attention was different first between language and non-language, second between the auditory and visual modalities, and lastly between deviant and standard stimuli. In other words, the processing location of attention varied along with verbal/non-verbal stimulus, modality and stimulus type, such that it manifested a characteristic of plasticity.

3.3 The cause of attentive N1 enhancement

For the deviant stimuli, the present experimental result showed that attended N1 was significantly larger than unattended N1 at central-frontal midline in auditory modality, and at two-lateral occipital area in visual modality. For the standard stimuli, the attentive N1 enhancement was over two-lateral occipital and posterior-temporal sites. As shown in fig. 1 and table 2, the locations of attentive N1 enhancement included the locations of the largest Nd1 peak under various conditions. Thus it is difficult to exclude attentive N1 overlapping with endogenous Nd1. For comparison of the onset time among attended N1, unattended N1 and Nd1 in the present results: (i) the onset of Nd1 was significantly earlier than that of unattended N1 at almost all electrode sites, regardless of modality and stimulus; (ii) the onset of attended N1 was earlier than that of unattended N1 at middle line and temporal sites of the scalp for the auditory standard and deviant stimuli, and at almost all sites for the visual standard stimuli. The attended N1 was also earlier than unattended N1 for the visual deviant stimuli, merely the difference did not attain the statistical significance, but the difference approached the significant level at O1 ($t=1.90$, $P<0.079$); (iii) regardless of modality or stimulus type, especially at almost all sites for auditory and visual deviant stimuli, the onset of Nd1 was earlier than that of the attended N1. That is, the attended N1 was later than Nd1 and earlier than unattended N1. Thus it is a reasonable inference that attended N1 is a mixed component including Nd1 and unattended N1. From the present experimental method it can be understood that unattended N1 is an exogenous component, the Nd1 is a pure endogenous attention component. As mentioned above, the reason of attentive N1 enhancement has a lasting controversy regarding whether the early Nd is caused by a genuine enhancement of exogenous N1 component, or by an endogenous PN component overlapping with the exogenous N1 which was unaffected by attention[6—8]. The present experimental results were consistent with our non-verbal experimental results[16] in supportng the viewpoint that N1 enhancement in attention is caused by endogenous component overlapping with exogenous component rather than by genuine exogenous component.

3.4 Evidence supporting early selection theory

The controversy whether there is early or late selection is one unresolved question of basic theories in attention psychology[6—8]. The division of early and late selective models is that the selection takes place either before or after accomplishing perception, respectively[9]. As mentioned above, the present results showed that the attended N1 was later than endogenous Nd1 but earlier than exogenous unattended N1. In other words, attention effect takes place before the exogenous component (which is elicited by stimulus itself, not by mental factor) does, thus providing evidence to support the early selection theory. This conclusion is consistent with our previous nonverbal result[16].

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